Higgs and Supersymmetry

Orsay, 19-23 march, 2001

Charged Higgs at LHC

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How to look for $H^{\pm}$ at LHC

i) if $m_{H+} < m_{top}$

use $t\bar{t}$ production with $t \to bH^{\pm}$, $H^{\pm} \to \tau\nu$ $(c\bar{s})$

ii) if $m_{H+} > m_{top}$ (more interesting)

production studied in detail up to now:

$gg \to tbH^{+}$

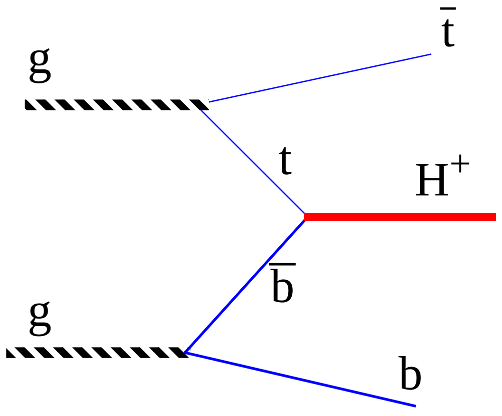
followed by $H^{+} \to \tau\nu$ or $H^{+} \to tb$

largest reach obtained in $H^{+} \to \tau\nu$, $\tau \to$ hadronic decay ("τ-jet")

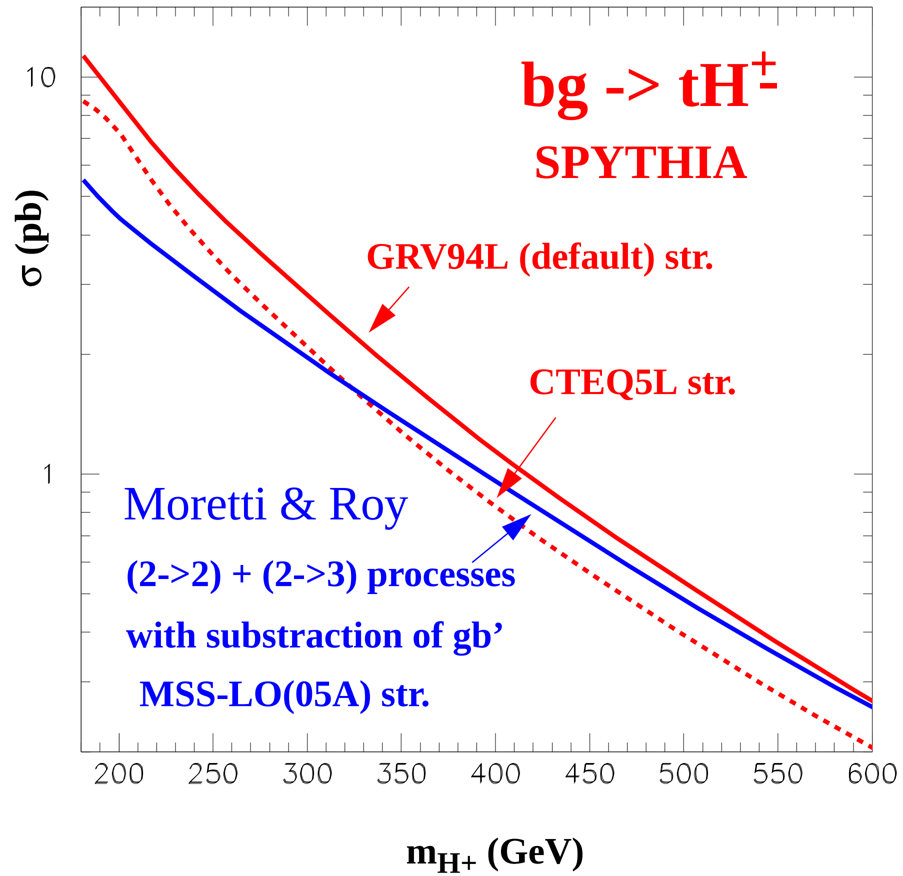
In some cases ($\gamma\gamma$, $b\bar{b}$) the neutral Higgs bosons may be hard to distinguish from the Standard Model Higgs at LHC $\rightarrow$

Observation of a charged Higgs would clearly signal that there is physics beyond SM (SUSY)

H^+ production in gb -> $tH^\pm$ and gg -> $tbH^\pm$

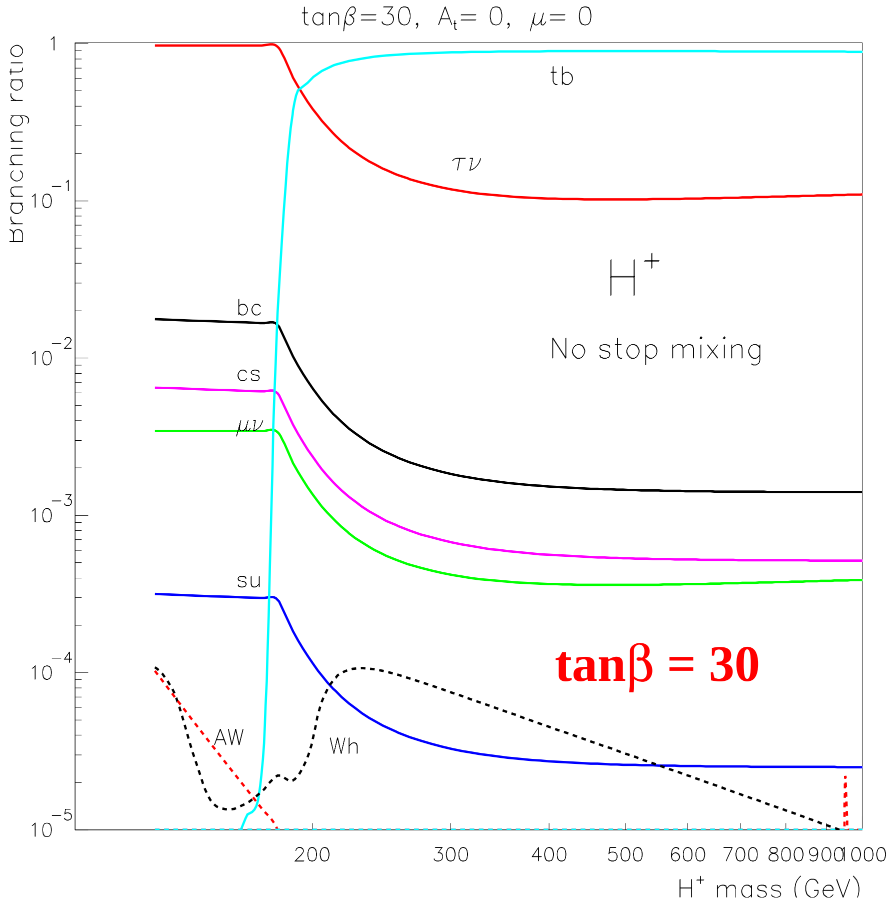


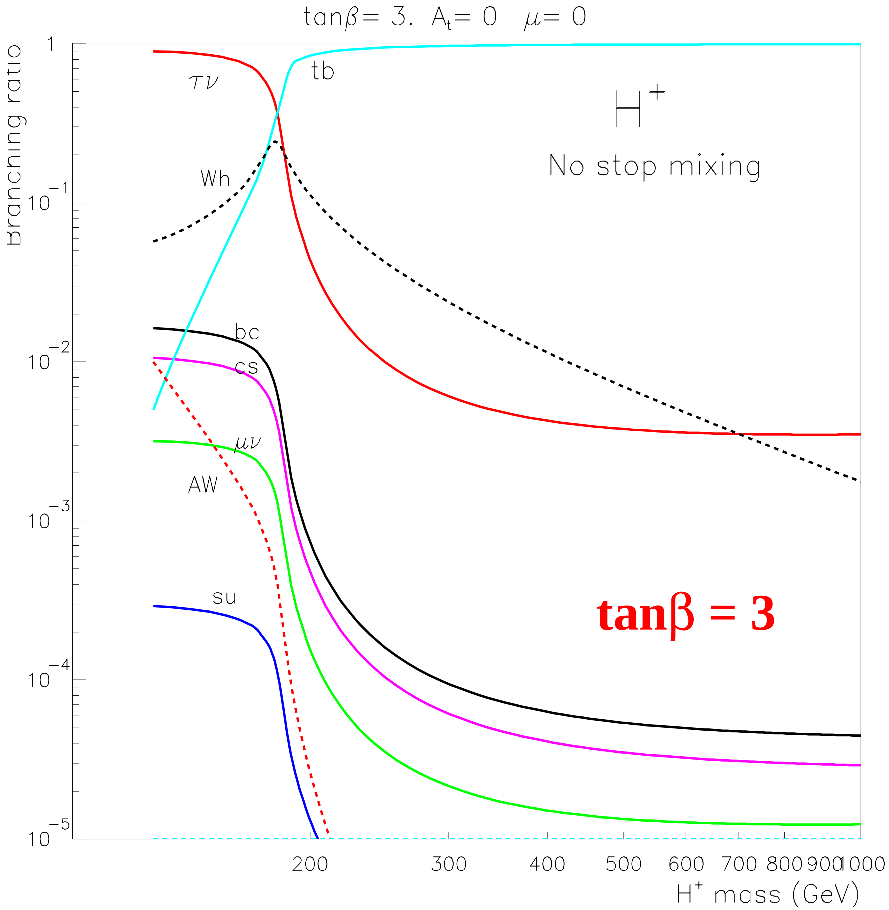
Good agreement between PYTHIA and theory for $m_{H+} \gtrsim 300$ GeV



Branching ratios for H^+, HDECAY

no stop mixing

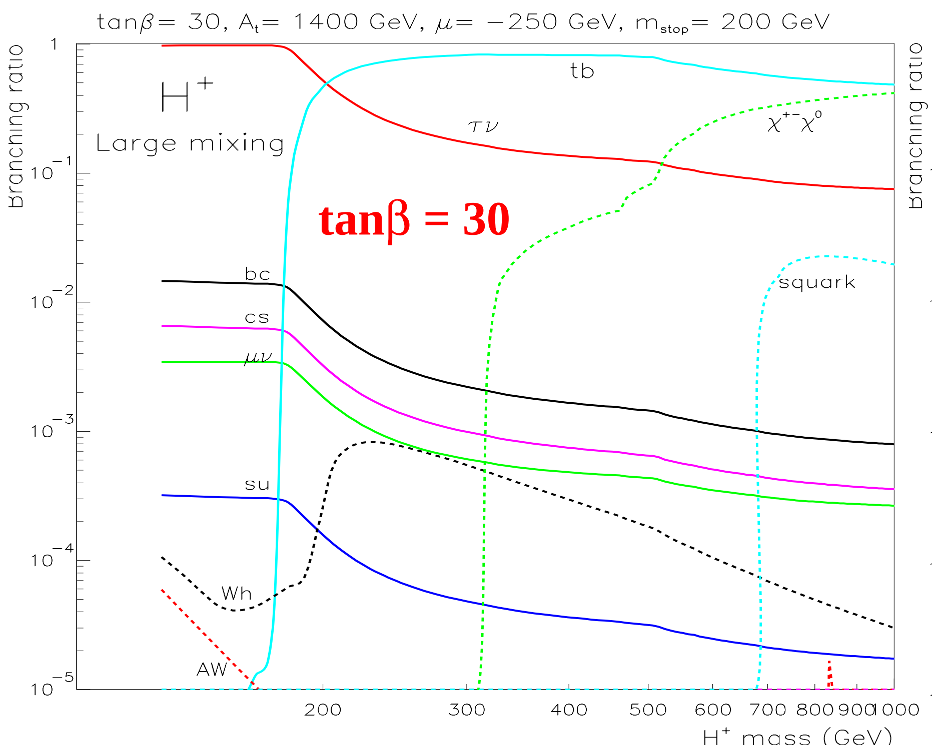


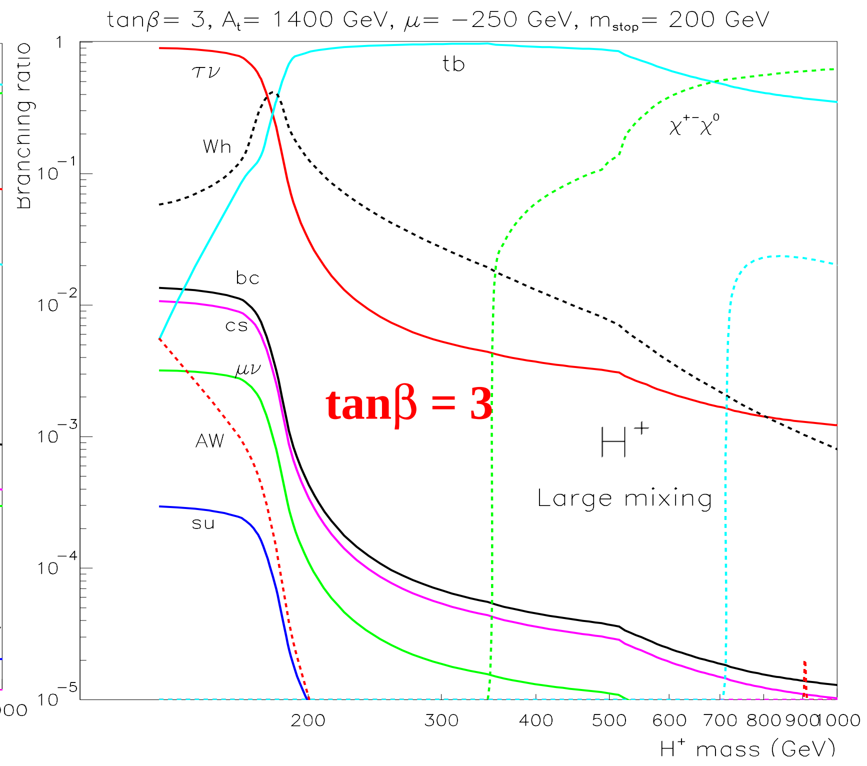


Branching ratios, H^+

Example with large stop mixing and light stop: A_t = 1400 GeV, m_{stop} = 200 GeV

Appearence of sparticle decay modes





$H^{\pm}$ -> $\tau\nu$ in $tbH^{\pm}$ production

- Signal and backgrounds generated with PYTHIA
  + TAUOLA to account for τ-spin correlations

- **Main backgrounds considered:**
  $t\bar{t}$, Wtb, W+jets

Detector response simulation:

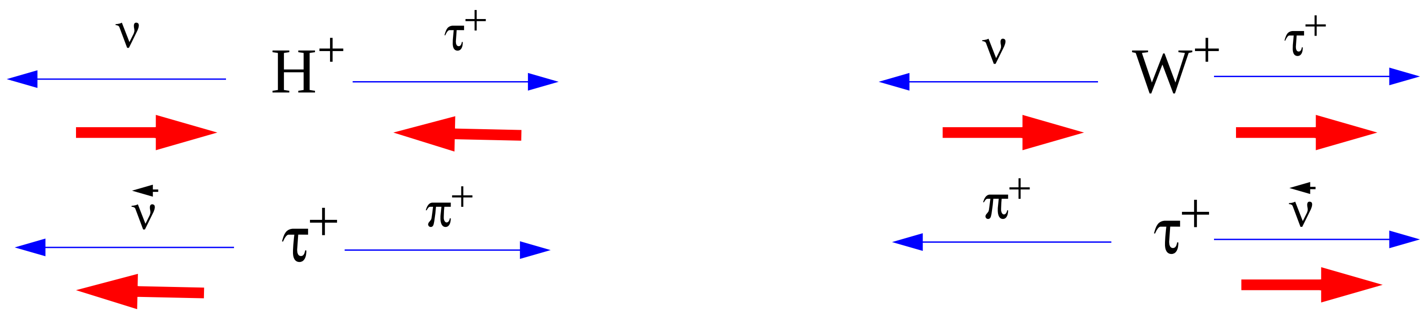
i) b-tagging aspects studied in detail with CMSIM and parametrized for fast simulation

ii) fast CMS detector simulation (CMSJET)

It turns out that $H^{\pm}$ -> $\tau\nu$ with $\tau \to \pi^{\pm} + \nu$ is the most promising channel thanks to the spin correlations in this mode as pointed out to us by D.P. Roy

τ polarization in $H^+ \to \tau\nu$

Spin correlations in $\tau^+ \to \pi^+\nu$ from $H^+ \to \tau^+\nu$ and $W^+ \to \tau^+\nu$:



$H^+ \to \tau^+\nu$ leads to harder pions from $\tau^+ \to \pi^+\nu$ and from the longidutinal components of ρ and a_1 than the corresponding decays in $W^+ \to \tau^+\nu$

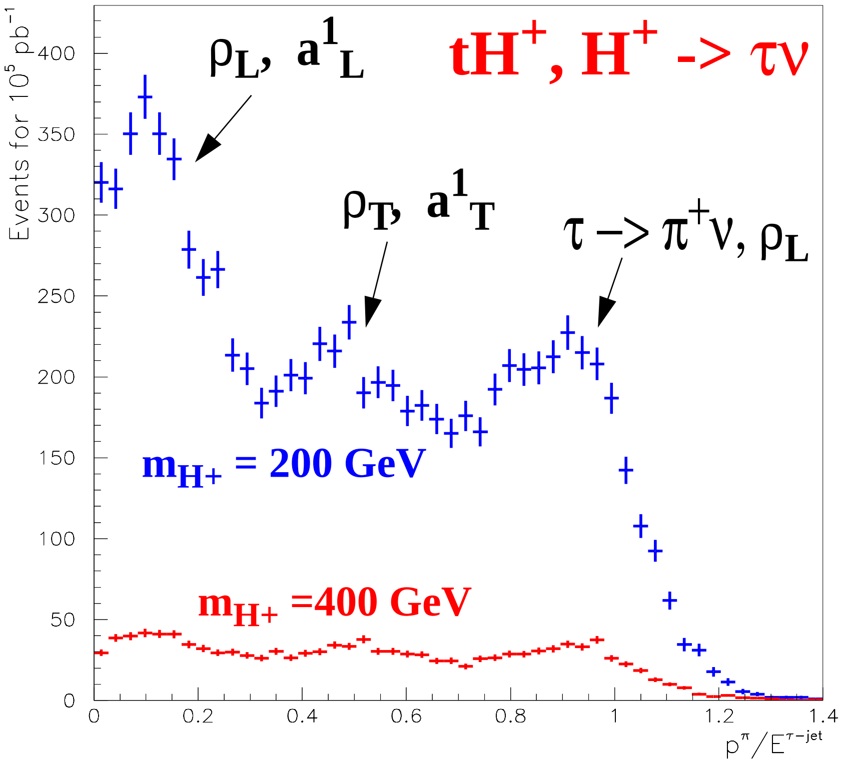
Main contributions to 1-prong τ decays:

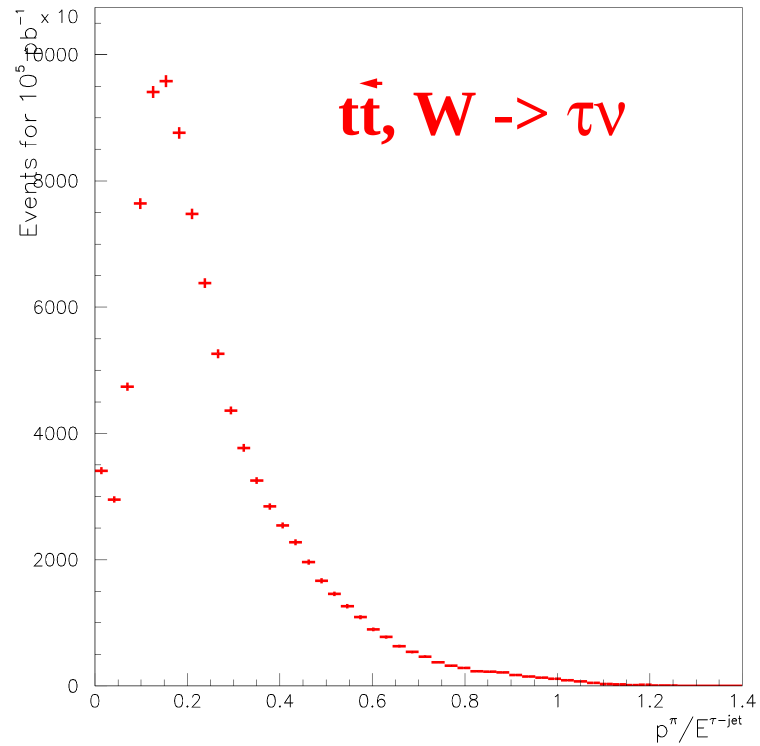
$\tau^+ \to \pi^+\nu$	12.5%
$\tau^+ \to \rho^+\nu \to \pi^+\pi^0\nu$	26%
$\tau^+ \to a_1\nu \to \pi^+\pi^0\pi^0\nu$	7.5%

Fraction of τ-jet energy carried by a single pion

τ decay with TAUOLA, all hadronic τ decay channels included

Reconstructed τ-jets, $E_t^{\tau\text{-jet}} > 100$ GeV





Large background reduction is obtained with the τ selection:

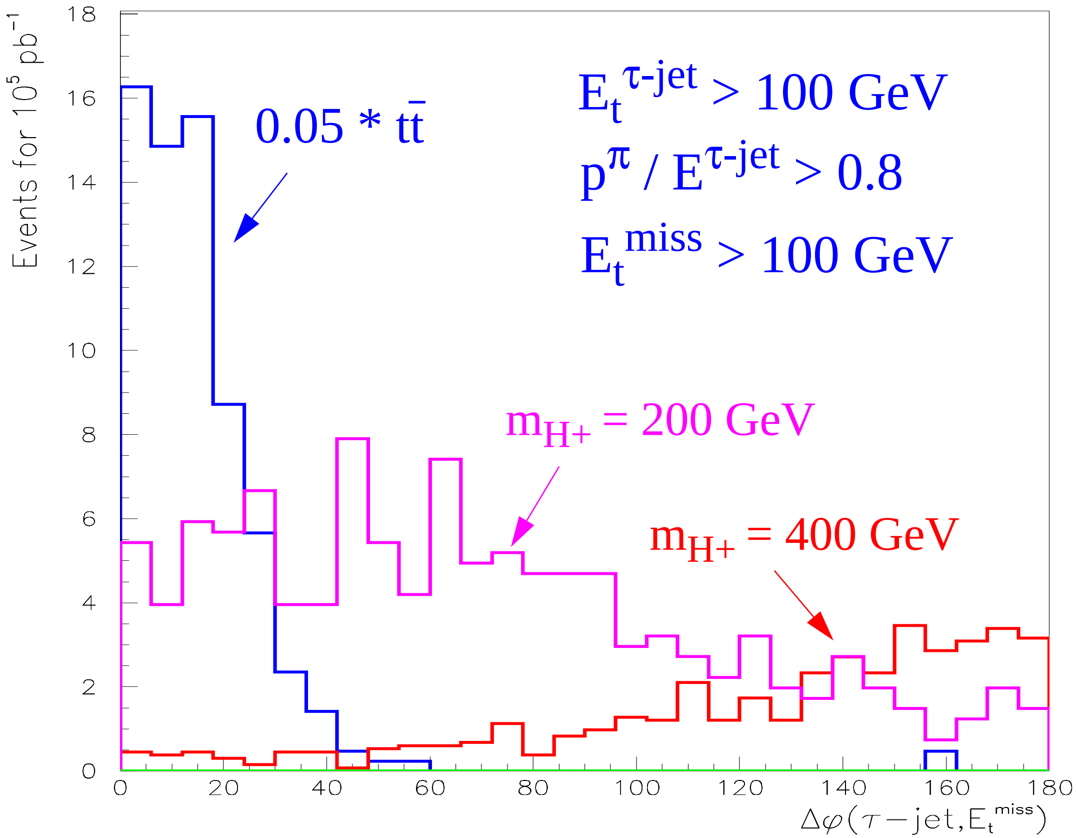
Selection efficiency for	H^+ (200,15)	H^+(400,23)	$t\bar{t}$
$\mathbf{E_t^{\tau\text{-jet}} > 100\ GeV}$	28.1%	65.4%	8.2%
$\mathbf{p^{hadron} / E^{\tau-jet} > 0.8}$	26.4%	27.4%	5.2%
Total τ selection	7.4%	17.9%	0.4%

Event selection for tbH^+, $H^+ \to \tau\nu$, $\tau \to$ hadron + X, $t \to$ jets

τ selection:	jet, $E_t > 100$ GeV, $\lvert \eta \rvert < 2.5$ containing one track with $r = p^h / E^{jet} > 0.8$, $\Delta R(jet,track) < 0.1$
Missing E_t cut:	$E_t^{miss} > 100$ GeV
W and top mass reconstruction:	in addition 3 jets (excluding τ-jet) with $E_t > 20$ GeV minimization of $\chi = (m_{jj} - m_W)^2 + (m_{jjj} - m_{top})^2$ $\lvert m_{jj} - m_W \rvert < 20$ GeV, 110 GeV $< m_{jjj} <$ 220 GeV
B-tagging:	jet not assigned to W is b-jet canditate: $E_t > 30$ GeV, efficiency of 50% for b-jets, 1.3 % for non-b-jets assumed
Selection further improved by:	
Second top veto:	$m(\tau\text{-jet}, E_t^{miss}, \text{jet}) > 300$ GeV
$\Delta\phi$-cut	$\Delta\phi(\tau\text{-jet}, E_t^{miss}) > 60^0$

$\Delta\phi(\tau\text{-jet}, E_t^{miss})$

$10^4 pb^{-1}$ with a pileup of 2 min. bias events superimposed

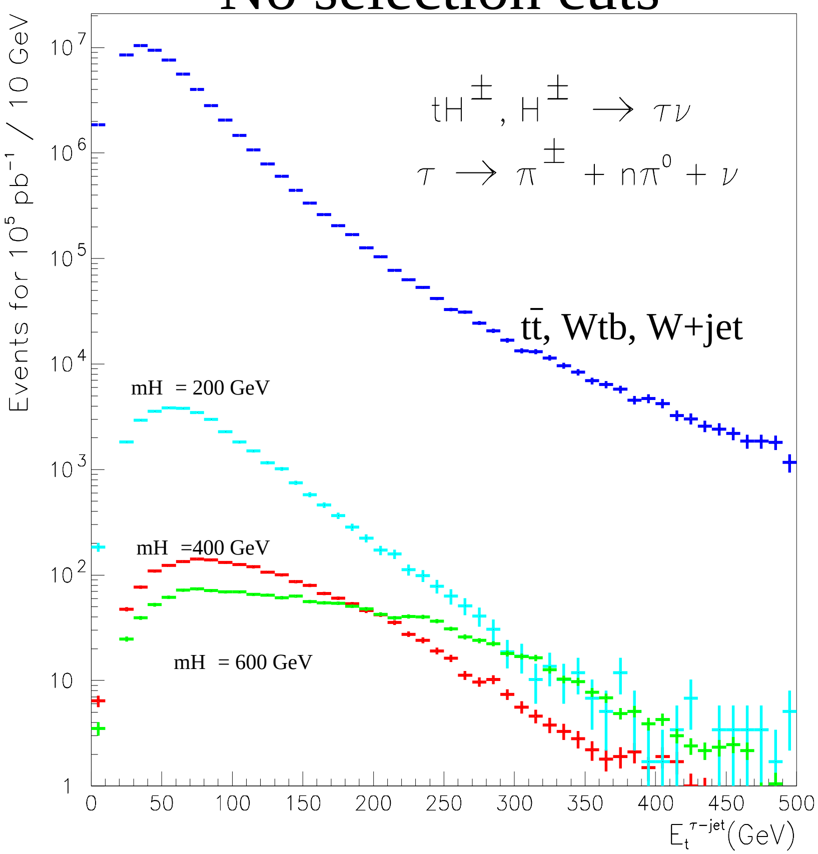


Small opening angle for $t\bar{t}$ background due to hard E_t cuts and hadronic decay of the associated top

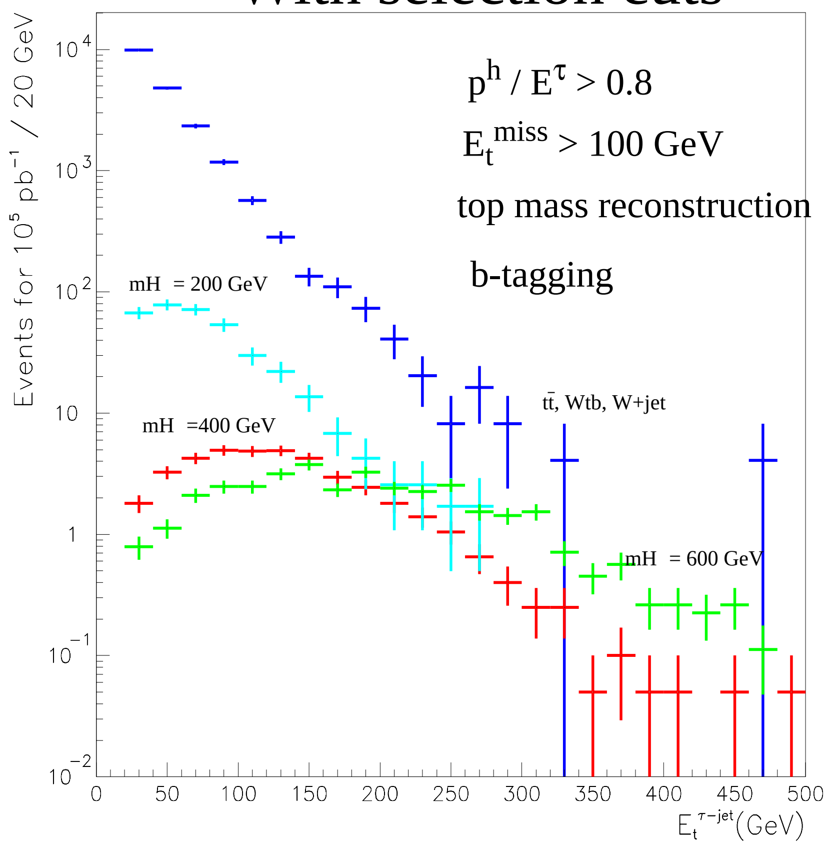
For $\Delta\phi(\tau\text{-jet}, E_t^{miss}) > 60^o$ almost background-free signal can be obtained

Reconstructed τ-jet

No selection cuts



With selection cuts



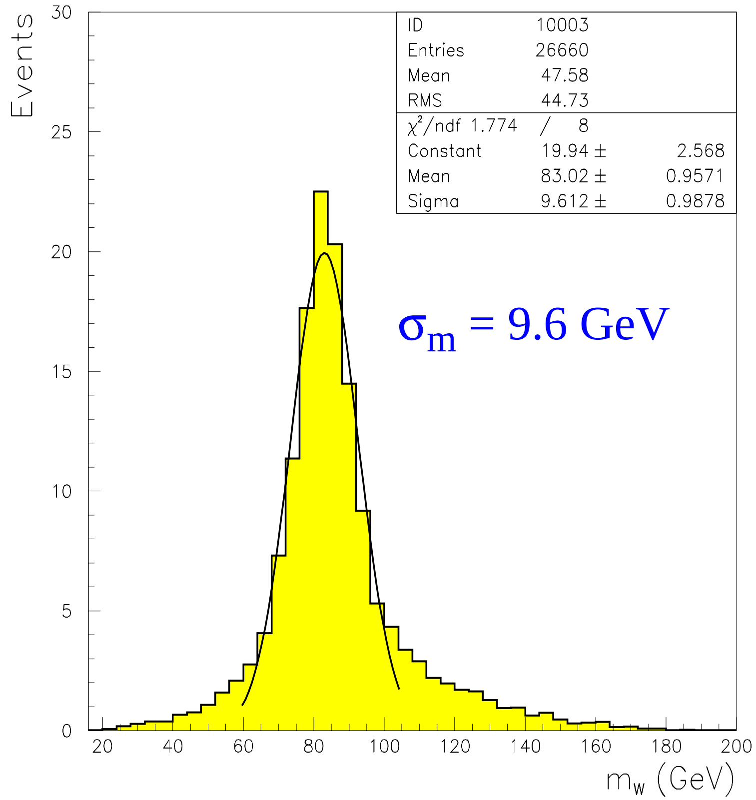
Signal not visible ->

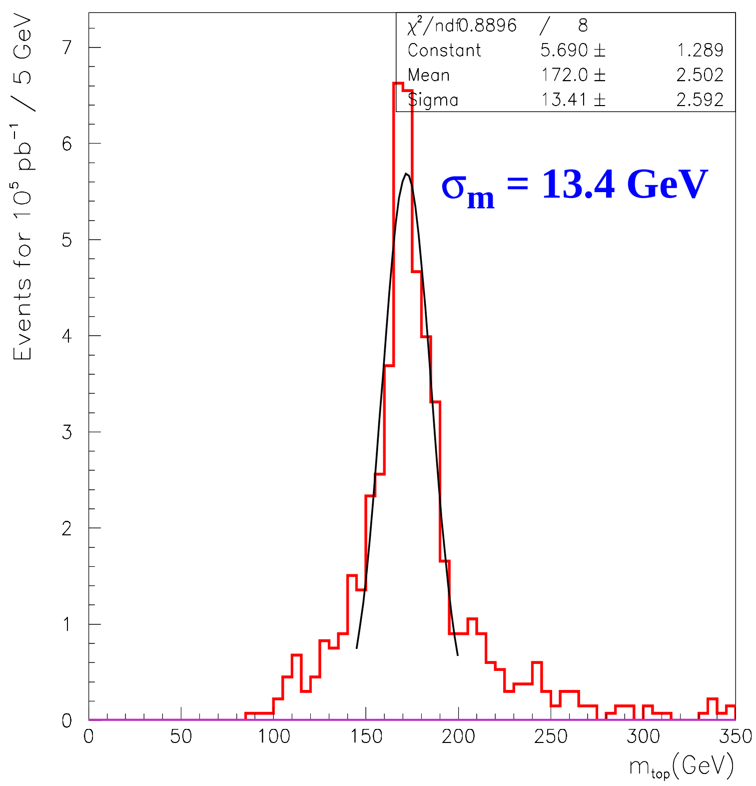
look for $m_T(\tau\text{-jet}, E_t^{miss})$

Top and W mass

Reconstructed minimizing $(m_{jjj} - m_{top})^2 + (m_{jj} - m_W)^2$

pileup of 2 minimum bias events superimposed



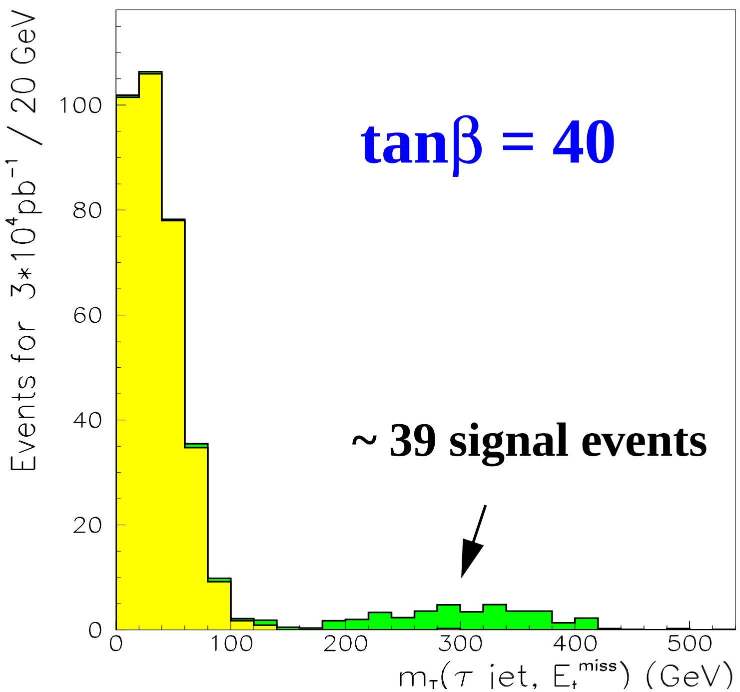


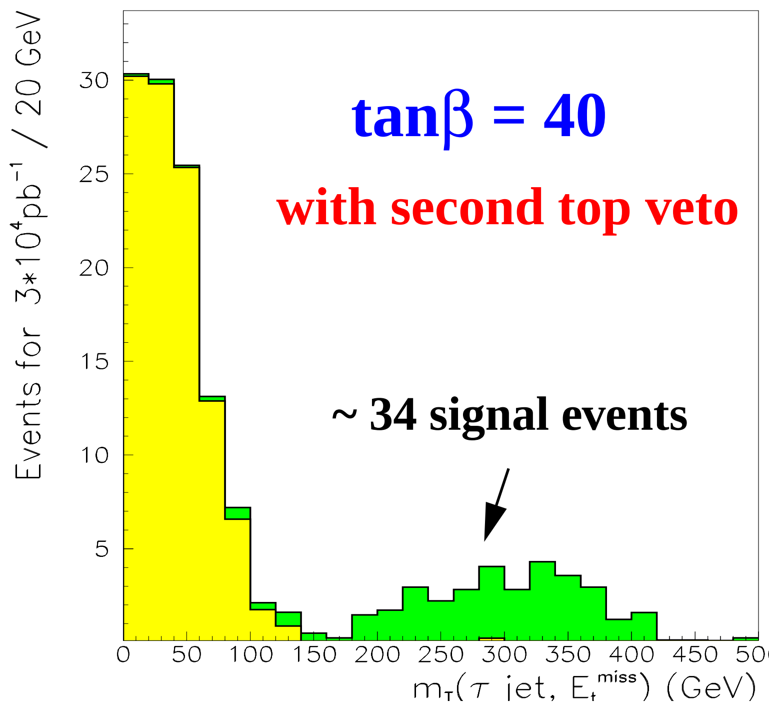
Efficiency for selection cuts, signal and backgrounds, $10^{33}cm^{-2}s^{-1}$

m_{H+},tanβ	(200,15)	(400,23)	$t\bar{t}$	Wtb	W+jet
E_t > 100 GeV	28.1%	65.4%	8.2%	3.9%	3.7%
p^h/ E^{jet} > 0.8	26.4%	27.4%	5.2%	5.9%	9.6%
total τ selection	7.4%	17.9%	0.4%	0.2%	0.36%
E_t^{miss} > 100 GeV	28.7%	74.7%	37.6%	28.4%	42.1%
W and top mass reconstruction:	42.7%	38.9%	46.1%	30.9%	6.5%
B-tagging	50%	50%	50%	50%	1.3%
Second top veto	87.7%	95.6%	47.0%	77.5%	75.3%
$\Delta\phi(\tau\text{-jet},E_t^{miss})>60^o$	53.2%	90.3%	-	-	-

Signal superimposed on the total background, $3*10^4 pb^{-1}$

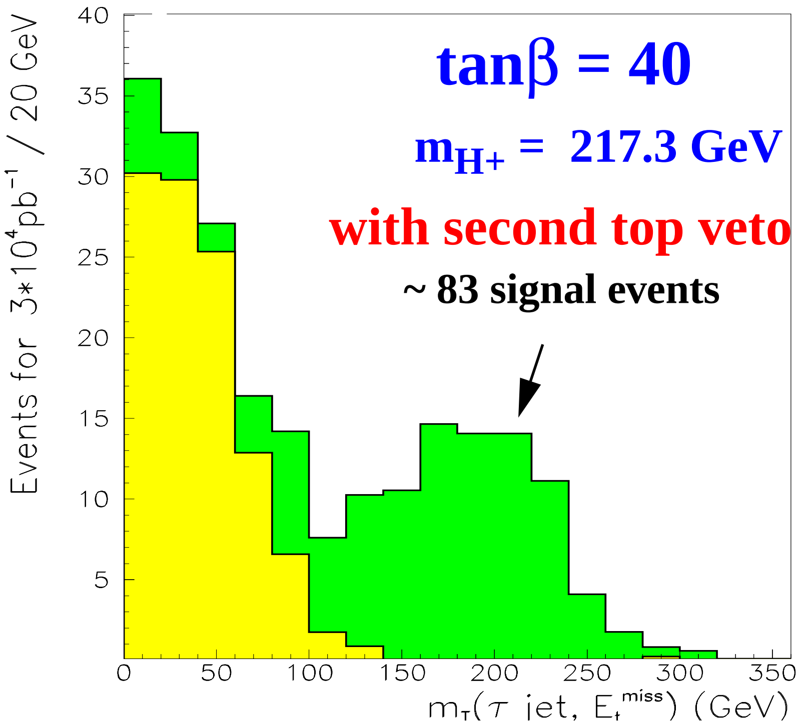
with basic selection cuts, m_A = 400 GeV



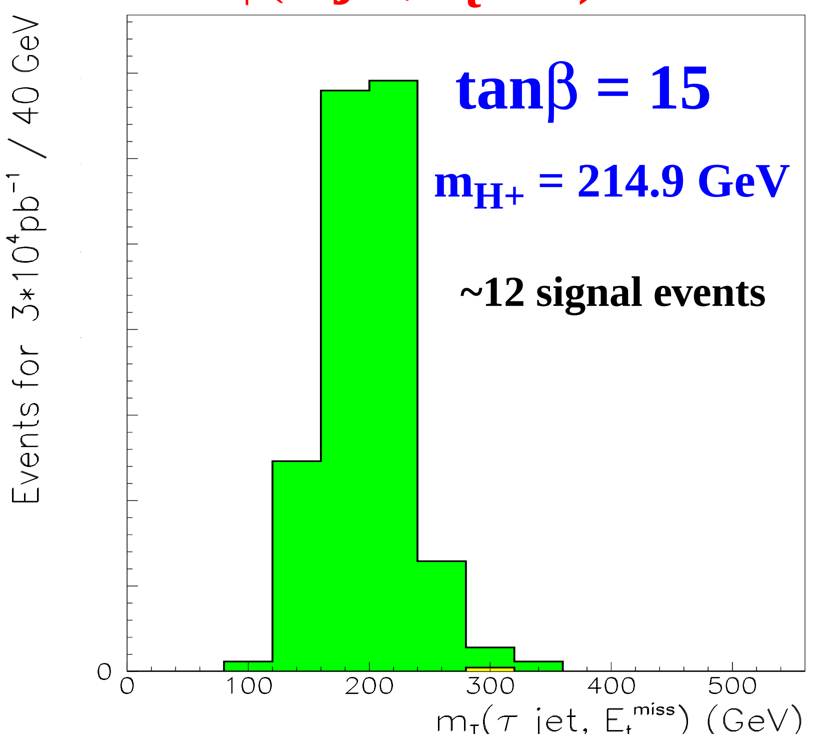


Signal superimposed on the total background, $3*10^4 pb^{-1}$

with selection cuts for m_A = 200 GeV



$\Delta\phi(\tau\text{-jet}, E_t^{miss}) > 60^o$



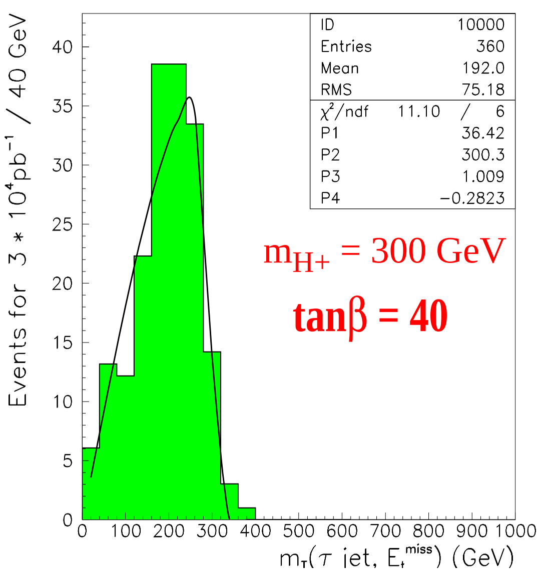
Events for signal and backgrounds for $3*10^4 pb^{-1}$ with selection cuts

	$m_T^{\tau\nu}$>100 GeV	$m_T^{\tau\nu}$>100 GeV m_{top2} > 300 GeV	$\Delta\phi(\tau\text{-jet},E_t^{miss}) > 60^o$
Signal, m_A = 200 GeV, tanβ = 15	17.0	13.1	12.5
Signal, m_A = 400 GeV, tanβ = 23	10.7	9.6	10.2
Signal, m_A = 600 GeV, tanβ = 40	11.0	10.2	10.6
$t\bar{t}$	2.4	2.4	< 0.8
W+jet	< 0.6	< 0.6	< 0.6
Wtb	< 0.2	< 0.2	< 0.2
Total background	2.4	2.4	< 1

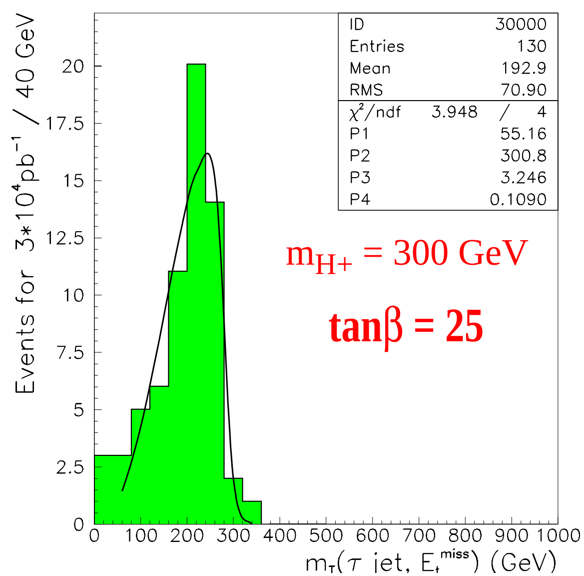
H^+ mass determination from $m_T(\tau\text{-jet},E_t^{miss})$

A 4-parameter fit of the form: $dN / dm_T \sim \int D(z)\, dz / \sqrt{M_{fit}^2 - m_T^2}$

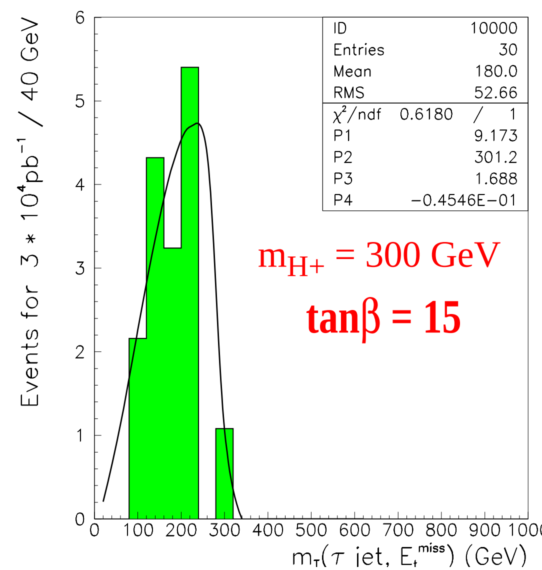
with $D(z) \sim z^{\alpha} (1 - z)^{\beta}$, $z = p_t^{\tau\text{-jet}} / p_t^{\tau}$



M_{fit} = 300.3 + 0.4 GeV



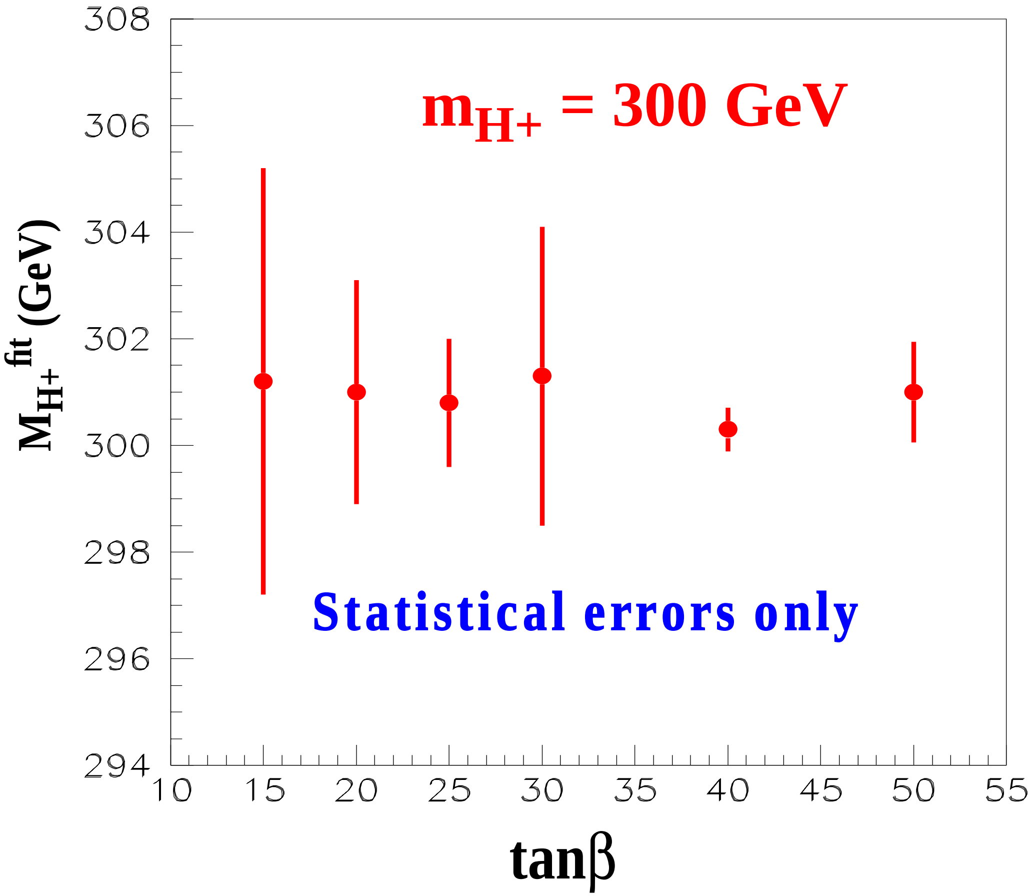
M_{fit} = 300.8 + 1.2 GeV



M_{fit} = 301.2 + 4.0 GeV

H^+ mass determination as a function of $\tan\beta$

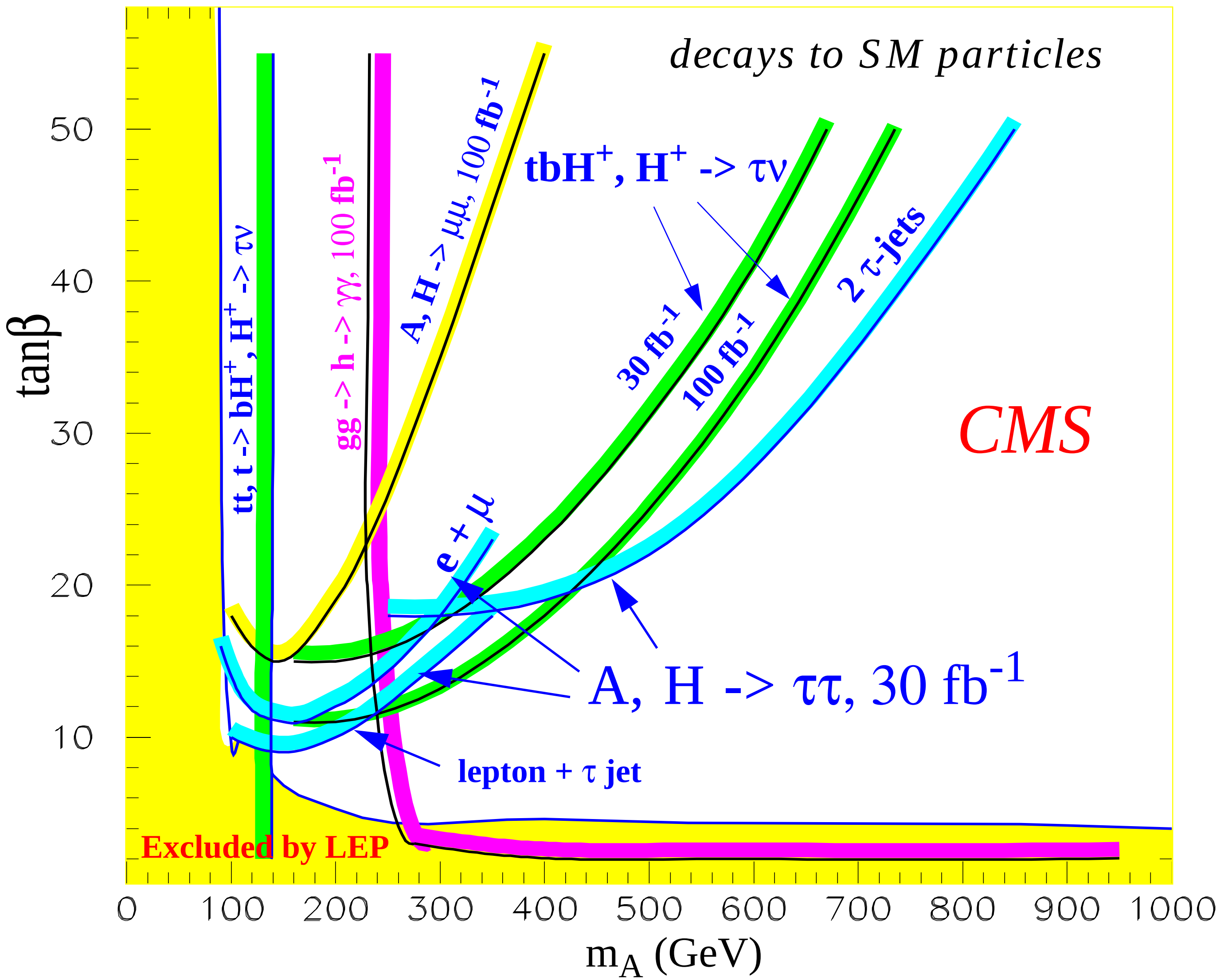
in tbH^+, $H^+ \to \tau\nu$



Systematic errors from energy scale for jets and E_t^{miss} measurement

$W \to \tau\nu$ may be used to determine the mass scale of $m_T(\tau\text{-jet}, E_t^{miss})$ measurement

5σ significance contours for SUSY Higgses



ATLAS Potential for $H^{\pm}$

Relevant channels for ATLAS:

$$
\begin{aligned}
H^{\pm} &\rightarrow \tau\nu \\
&\rightarrow tb,\ t^{*}b \\
&\rightarrow Wh,\ W^{*}h
\end{aligned}
$$

Production: $m_{H^{\pm}} < m_t$

$$
\begin{aligned}
pp &\longrightarrow t\bar{t} \\
t &\longrightarrow H^{\pm}b \\
\bar{t} &\longrightarrow Wb
\end{aligned}
$$

Production: $m_{H^{\pm}} > m_t$

$$
\begin{aligned}
gb &\longrightarrow tH^{\pm} \\
gg/qq' &\longrightarrow tH^{\pm}b
\end{aligned}
$$

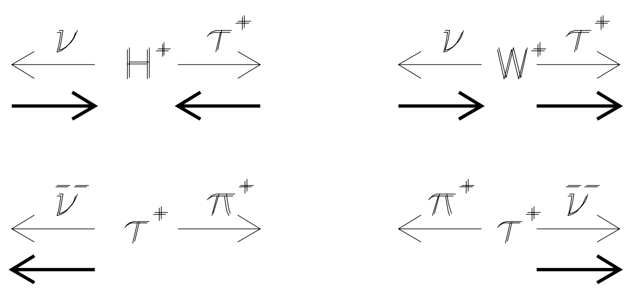
With $t \longrightarrow Wb$. For final states up to 3 b-tags, both processes contribute.

$pp \to tH^{\pm},\ t \to jjb,\ H^{\pm} \to \tau\nu_\tau\,(m_{H^\pm} > m_t)$

Thus requires a multi-jet trigger and a $\tau-$trigger!
Also good τ identification efficiency and jet rejection

- Signal, $H^{\pm} \to \tau^{+}\nu$: $\tan\beta = 40$, $m_{H^\pm} = 250$ GeV, $\sigma \times$ BR $= 0.91$ pb.
- Backgrounds:
  - $pp \to t\bar{t} \to WbWb$, $\sigma \times$ BR $= 84$ pb
  - $pp \to W +$ jets, $\sigma \times$ BR $= 1.64\,10^4$ pb

  with one $W \to \tau\nu$ and the other $W \to jj$
- Take advantage of differences in τ polarizations:
  For 1-prong decays,

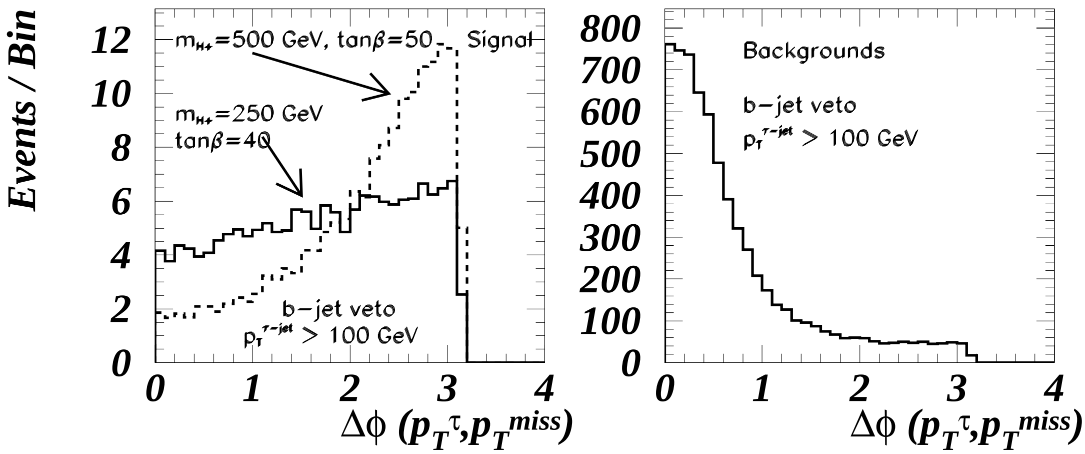


Harder π from $\tau \to \pi\nu$ and
longitudinal ρ and a_1 in H^+ than W^+

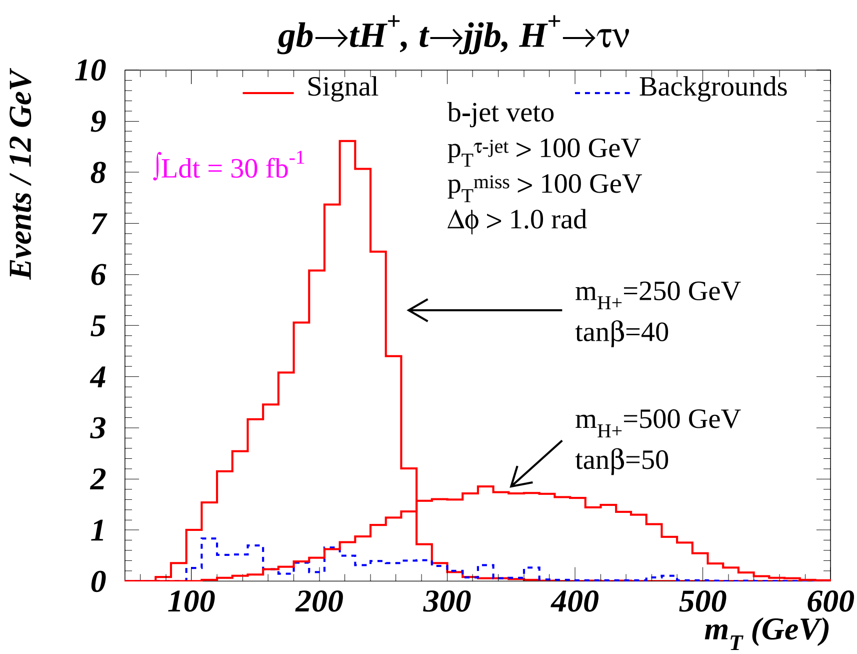
Use inclusive τ decays (not just 1-prong) but with τ-polarization

$pp \to tH^\pm,\ t \to jjb,\ H^\pm \to \tau\nu_\tau\ (m_{H^\pm} > m_t)$

- Take advantage of differences in kinematics



- Reconstruct the transverse mass



- Channel almost background free. Discovery limited by signal size itself. Reach extended to $\sim$ 700 GeV, $\tan\beta > 10$!

$t \to bH^{\pm} \to b\tau^{\pm}\nu \; (m_{H^{\pm}} < m_t)$

- Signal:

$$\begin{array}{rcl} pp & \to & t\bar{t} \\ t & \to & bH^{\pm} \to b\tau^{\pm}\nu_{\tau} \to b\text{hadrons}\,\nu_{\tau} \\ \bar{t} & \to & bW^{\pm}\,(H^{\pm}) \to bl^{\pm}\nu_l\,(l^{\pm}\nu_l\nu_{\tau}) \end{array}$$

- Backgrounds: $pp \to t\bar{t}$, $W+$jets, $b\bar{b}$
- Search for 1 hadronic τ, 1 isolated lepton, $\geq$ 3 jets (with 2 b-tagged)
- $m_{H^{\pm}}$ cannot be reconstructed. Signal appears as an excess of τ leptons
- $\tan\beta = 5$ and $m_{H^{\pm}} = 130$ GeV, $\sigma \times \text{BR} = 13.1$ pb

  $\sim$1200 τ from $H^{\pm}$

  $\sim$2500 τ from $W^{\pm}$

  $\sim$3400 fake τ's

  Significance $= 6.6$ (3% systematics on fake τ efficiency)

- Discovery possible for $m_{H^{\pm}} < m_t - 20$ GeV over most of the $\tan\beta$ range.

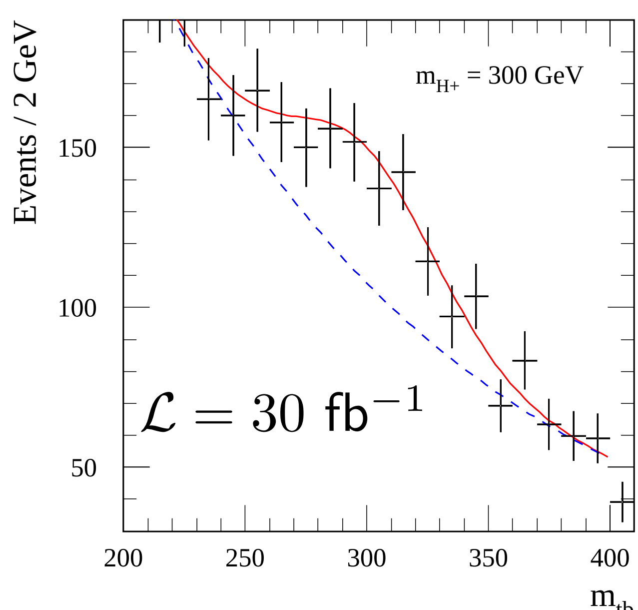
$pp \rightarrow tH^{\pm}$ $(m_{H^{\pm}} > m_t)$

$H^{\pm} \rightarrow \bar{t}b$, $t \rightarrow Wb \rightarrow l\nu_l b$ and $\bar{t} \rightarrow Wb \rightarrow jjb$

- Signal: $\tan\beta = 30$, $m_{H^{\pm}} = 250$ GeV, $\sigma \times$ BR $= 1.2$ pb.
- Background: $pp \rightarrow t\bar{t}b$, $\sigma \times$ BR $= 228$ pb
- 1l, 3 b-tagged jets and at least 2 non b-jets
- $W \rightarrow l\nu$ and $W \rightarrow jj$
- $t_1 \rightarrow l\nu b_1$ and $t_2 \rightarrow jjb_2$ inside mass window
- Reconstruct $m_{t_1 b}$ and $m_{t_2 b}$

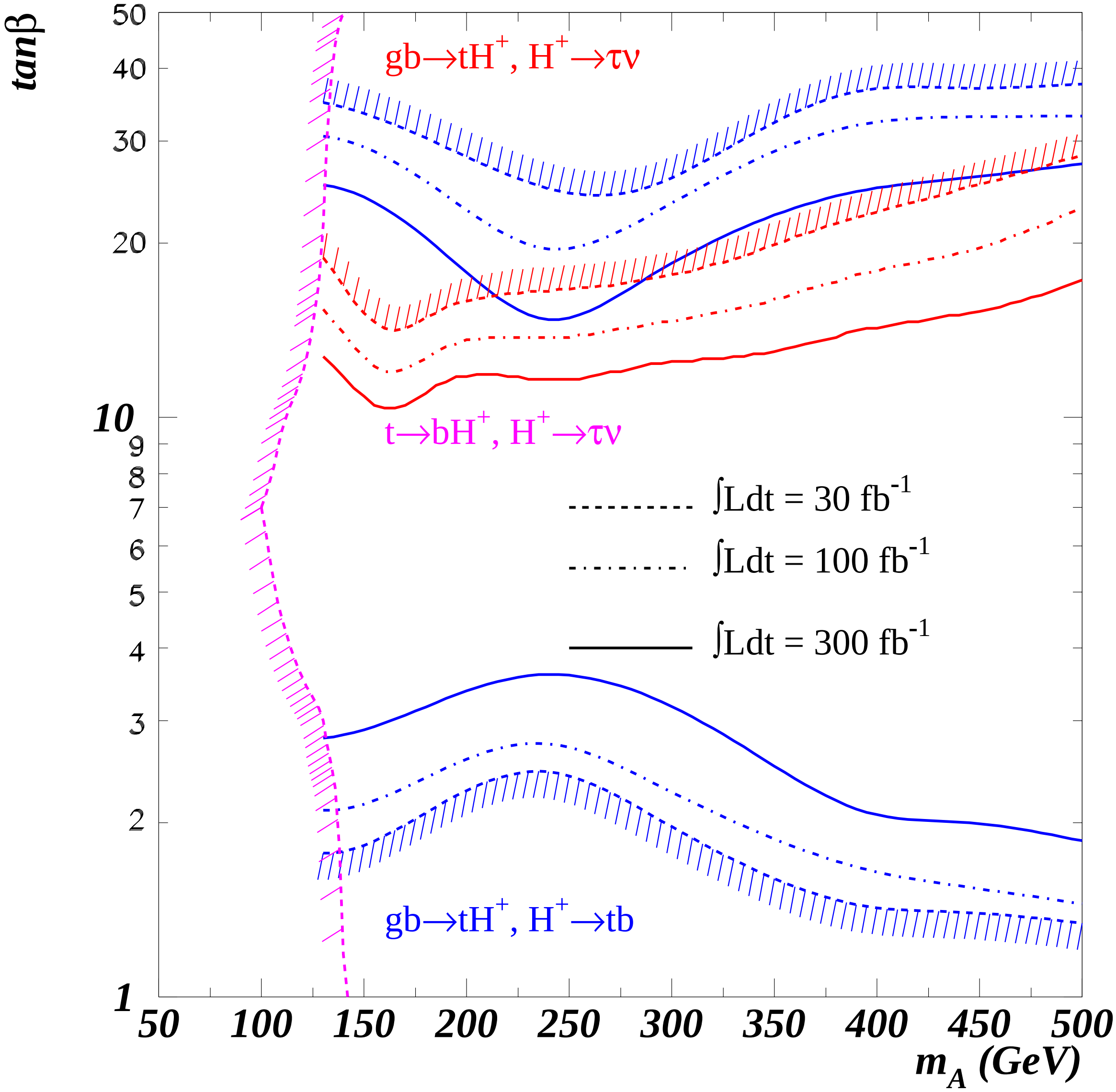
$\mathcal{L} = 30$ fb^{-1}, $\tan\beta = 30$ and $m_{H^{\pm}} = 250$ GeV:

- Signal $= 336$ events in $m_{H^{\pm}} \pm 2 \times 37$ GeV
- $S/B = 0.21$
- $S/\sqrt{B} = 8.4$



Discovery possible up to 400 GeV ($\tan\beta > 15$)

ATLAS discovery Potential for $H^{\pm}$



Discovery relies on: $H^{\pm} \rightarrow \tau\nu$ and on $H^{\pm} \rightarrow tb$

Charged Higgs via s-channel production in CMS

Production through: $q\bar{q}' \rightarrow H^{+} \rightarrow \tau\nu$

- Cross sections for signal and backgrounds

LO + NLO calculation including 2 -> 2 and 2 -> 3 processes

PYTHIA for fragmentation

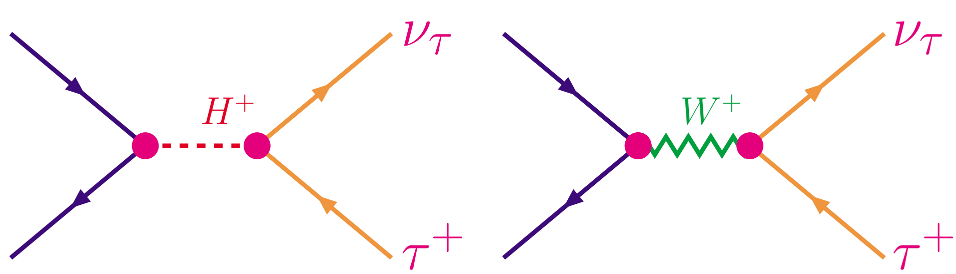
TAUOLA for τ polarization

CMSJET for detector simulation

• charged Higgs can be produced in s-channel process due to light quarks interaction

$$qq' \to H^{\pm}, \quad q(q') = d, u, s, c, b$$

• $H^{\pm} \to \tau\nu_\tau$ channel



• τ polarisation
for any $\tan\beta$ τ-lepton from $H^{\pm}$ decay has polarisation opposite to SM case

$$\mathcal{L}_{SM} \propto \bar{\nu}\ (P_R\gamma^\alpha P_L)\tau \quad \mathcal{L}_H \propto \bar{\nu}\ P_R\tau$$

$$\begin{array}{lllllll} \mathrm{SM} & \tau_L(\leftarrow) & \Rightarrow & \nu_L(\leftarrow)\pi & \Rightarrow & p_\pi \ll p_\tau,\ p_\nu \sim p_\tau \\ \mathrm{H} & \tau_R(\rightarrow) & \Rightarrow & \nu_L(\leftarrow)\pi & \Rightarrow & p_\pi \sim p_\tau,\ p_\nu \ll p_\tau \end{array}$$

- uncertainty in the cross section

s-channel production cross section, $q\bar{q}' \to H^{\pm}$, has large uncertainty due to masses of light quarks

$$\sigma(\bar{q}' \to H^{\pm}) \propto (m_u^2 \cot^2\beta + m_d^2 \tan^2\beta)$$

for $M_H = 300$ GeV and $\tan\beta = 30$

$m_d = m_u = 300$ MeV $\quad \sigma(H^{\pm} \to \tau\nu) \approx 1.6$ pb

$m_d = 9$, $m_u = 5$ MeV $\quad \sigma(H^{\pm} \to \tau\nu) \approx 0.07$ pb

- we use RPP values for m_q

$m_d = 9$ MeV $\quad m_s = 150$ MeV $\quad m_b = 4.8$ GeV

$m_u = 5$ MeV $\quad m_c = 1.25$ GeV

$M_H = 200$ GeV and $\tan\beta = 30, \quad 60$

$\tan\beta$	1	10	30	50
Γ, GeV	2.83	0.26	2.3	6.6
Br, %	0.015	16	16	16
σ, pb	3×10^{-5}	0.078	0.85	2.1

- background processes

◇ $W^{\pm}(\to \tau\nu)$

two intervals on $\sqrt{\hat{s}}$ are used

$W(W)$: 30 GeV $< \sqrt{\hat{s}} <$ 150 GeV and

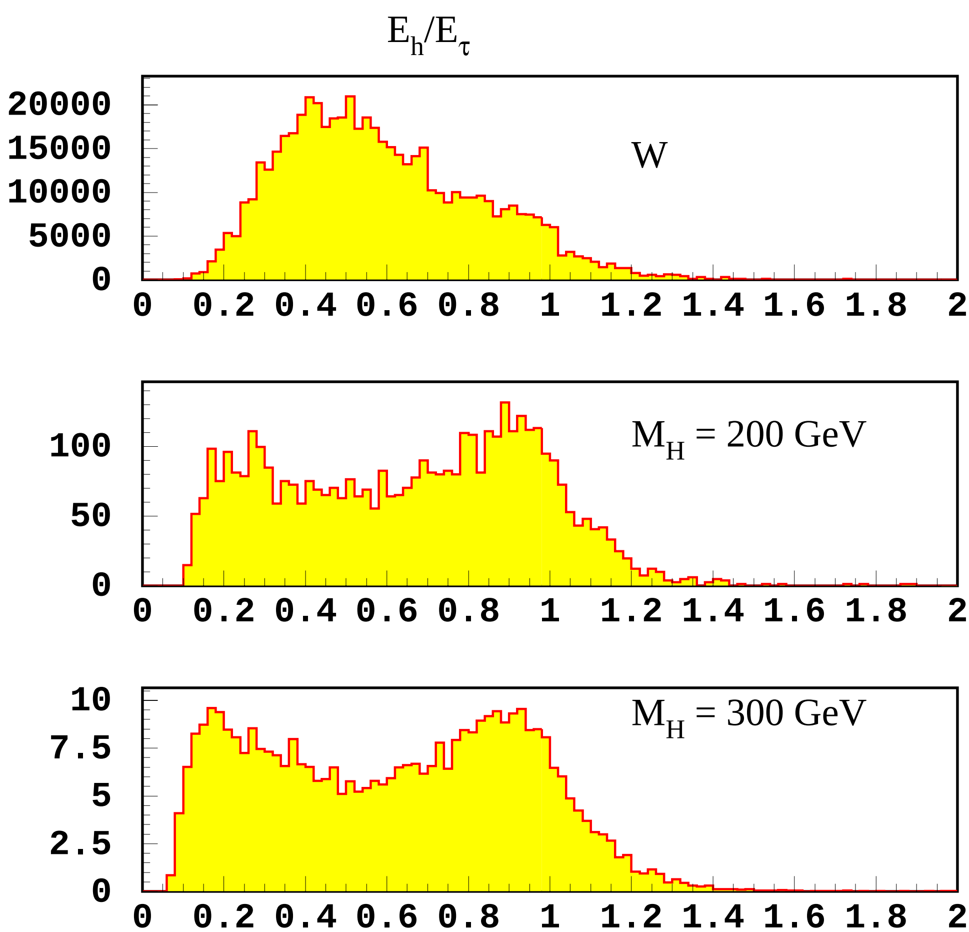
$W(H)$: 150 GeV $< \sqrt{\hat{s}} < \sqrt{S_{pp}}$

◇ $t\bar{t}$ production

◇ $Wb\bar{b}$ production

$k_{\perp min} = 10$ GeV, $\sqrt{\hat{s}_{cut}} = 150$ GeV

	P_0	$\sigma(2 \to 2)$	$\sigma(2 \to 3)$	σ_{tot}
$H^{\pm}$	19.4	0.85	0.73	1.0
$W^{\pm}(H)$	16.0	21.1	17.3	26.0
$W^{\pm}(W)$	11.4	1.8×10^4	1.6×10^4	2.4×10^4
$t\bar{t}$				830
$Wb\bar{b}$				400

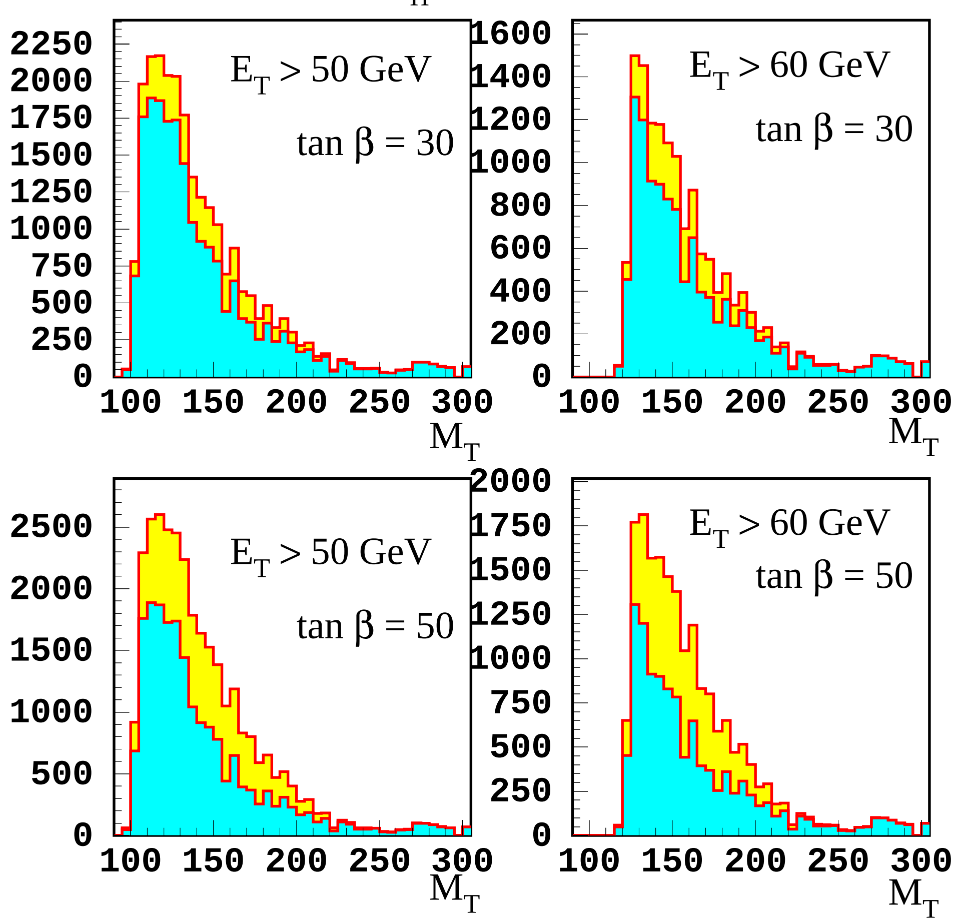

E_h/E_τ
20000
15000
10000
5000
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
W
100
50
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
M_H = 200 GeV
10
7.5
5
2.5
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
M_H = 300 GeV

- signal/background separation
  - ◇ explicitly one τ-jet,
    one charged prong
    $E_{prong} > 10$ GeV, $R_{cone} = 0.4$, $r_{ECAL} = 0.15$,
    $E_{ECAL}/E_{TOT} > 0.92$
  - ◇ $R_H = E_{prong}/E_\tau > 0.85$
  - ◇ no additional hadronic jets with $P_\top(J) > 20$ GeV
  - ◇ $E_{Tmis}, E_{T\tau} > 50, 60$ GeV
- $\int \mathcal{L} = 30$ fb^{-1}, $M_H = 200$ GeV, $R_H > 0.85$

cut	Bkg	30	$\frac{S}{S+B}$	50	$\frac{S}{S+B}$
R_H	3.3×10^6	1366	0.75	3304	1.82
$E_T > 50$	2872	505	9.2	1222	22.8
$E_T > 60$	1693	350	8.55	848	20.6

$$M_{\top} = 2 P_{\top \tau} E_{T mis} (1 - \cos \phi_{\tau E_{T mis}})$$

m_H = 200 GeV



• signal and backgrounds have similar shapes
$W^{\pm}$ is produced mainly in light quarks annihilation, since $N(u,d) > N(\bar{u},\bar{d})$

$$\sigma(W^+) > \sigma(W^-) \Rightarrow N(\tau^+) > N(\tau^-)$$

$H^{\pm}$ is produced due to interaction of heavy s, c, b quarks, since $N(Q) = N(\bar{Q})$

$$\sigma(H^+) \approx \sigma(H^-) \Rightarrow N_H(\tau^+) \approx N_H(\tau^-)$$

$$A_\tau \equiv \frac{N(\tau^+) - N(\tau^-)}{N(\tau^+) + N(\tau^-)}$$

$R_H = 0.85$, $E50 \equiv E_T > 50$, $E60 \equiv E_T > 60$

cut	$A_\tau(W)$	$A_\tau(H)$, 30	$A_\tau(H)$, 50
R_H	0.11 ± 0.001	0.110 ± 0.001	0.110 ± 0.001
$E50$	0.189 ± 0.019	0.167 ± 0.017	0.145 ± 0.016
$E60$	0.234 ± 0.025	0.197 ± 0.023	0.163 ± 0.020

Conclusions

- Charged Higgs can be discovered in the process

  $gg \to tbH^+$, $H^+ \to \tau\nu$, $\tau \to$ hadrons$+\nu$, $t \to qqb$

  in a large part of the parameter space:

  $\tan\beta \gtrsim 10$ at $m_{H+} \sim 200$ GeV

  $\tan\beta \gtrsim 20$ at $m_{H+} \sim 400$ GeV

  - Mass determination may be possible with $\lesssim 2\%$ precision, preliminary result - systematics still to be understood

- With $H^+ \to tb$ discovery possible up to ~ 400 GeV, $\tan\beta > 15$

- $\Gamma(H^+ \to tb) / \Gamma(H^+ \to \tau\nu)$ could provide a measurement of $\tan\beta$